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NATURAL HISTORY AND METHODS OF CONTROLLING THE COMMON OYSTER DRILLS (*UROSALPINX CINEREA* SAY AND *EUPLEURA CAUDATA* SAY)[1]

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INTRODUCTION

Under the provisions of a special appropriation by Congress, the United States Bureau of Fisheries carried out extensive studies on the natural history and methods of controlling the common oyster drills in the Atlantic and Gulf States. In the course of these investigations, which lasted from April 1, 1935, to June 30, 1936, 38 persons

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were engaged for various periods of time to work under the immediate supervision of the authors; and 125 laborers supplied by various relief organizations were employed in large-scale trapping experiments. Because of the voluminous data, the publication of a complete scientific report cannot be made at the present time. It is considered, however, that a brief summary of the present observations and of the old data already published by the Bureau (Federighi, 1930, 1931), accompanied by a description of the recommended methods of control, will be useful to the oystermen and to persons interested in the protection of oyster bottoms from these destructive pests.

The principal experimental work on oyster drill control was carried out on the Eastern Shore of Virginia, in Delaware and Barnegat Bays, N. J., and on Cape Cod. Additional observations regarding the occurrence and distribution of these pests were made in Florida, South Carolina, North Carolina, Georgia, Connecticut, and Rhode Island. In every State the work of the Bureau of Fisheries was greatly facilitated by the excellent cooperation offered by the State authorities and the oystermen, whose assistance is gratefully acknowledged. Drill studies in Delaware Bay were carried out jointly with the State Agricultural Experiment Station under the supervision of Dr. Thurlow C. Nelson.

DISTRIBUTION AND DESTRUCTIVENESS OF OYSTER DRILLS

From Cape Cod to Florida the oyster bottoms of the coastal waters give refuge to hoards of small snails known to the oystermen as drills or screw borers and named by scientists, *Urosalpinx cinerea* Say and *Eupleura caudata* Say (fig. 1). They are very abundant on the rocky shores of New England and on oyster bottoms of Great South Bay, Delaware Bay, lower Chesapeake Bay, and Seaside, Va., but occur only sparingly in Georgia, South Carolina, Florida, and along the Gulf coast. Drills were introduced with the shipment of eastern oysters into San Francisco Bay; were reported from the Bermuda Islands and more recently (Orton, 1927; Orton and Wickworth, 1928) gave considerable concern to the oystermen in England where they appeared in large numbers on bottoms planted with imported American oysters.

To estimate in dollars and cents the extent of damages caused annually by these small denizens of the sea is not an easy task and no accurate figure for the whole area of their distribution is at present available. It is known, however, that the oystermen pay heavily for the ravenous appetite of the drills and that the annual damages caused by them exceed several million dollars. In Delaware Bay alone, according to Nelson (1931) more than $1,000,000 worth of oysters are killed annually by the drills. On the Eastern Shore of Virginia between Chincoteague and Cape Charles, it was estimated during the present study that $150,000 is the probable annual cost of destruction. There are many localities in Long Island Sound and in certain sections of the Chesapeake Bay where drills commonly kill 60 to 70 percent of seed oysters, and not infrequently annihilate the entire crop. In Buzzards Bay the destruction of over 80 percent of oysters during the first year of their life has been reported by Pope (unpublished data in files of the United States Bureau of Fisheries).

Judging by their ability to devour oysters, the two species of drills are about equally destructive, but *Urosalpinx*, because of its much greater abundance, should be considered at present the principal enemy. Consequently, the greater part of the observations described in this paper refer to this species.

LIFE HISTORY

GENERAL APPEARANCE

Although the two species of drills resemble each other in general appearance of their fusiform shell (fig. 1), their size and brown or gray color, they can be easily distinguished, even by an inexperienced observer, thus: The shell of *Urosalpinx* has rounded whorls while those of *Eupleura* are angulated. Furthermore, the shell of *Urosal-*

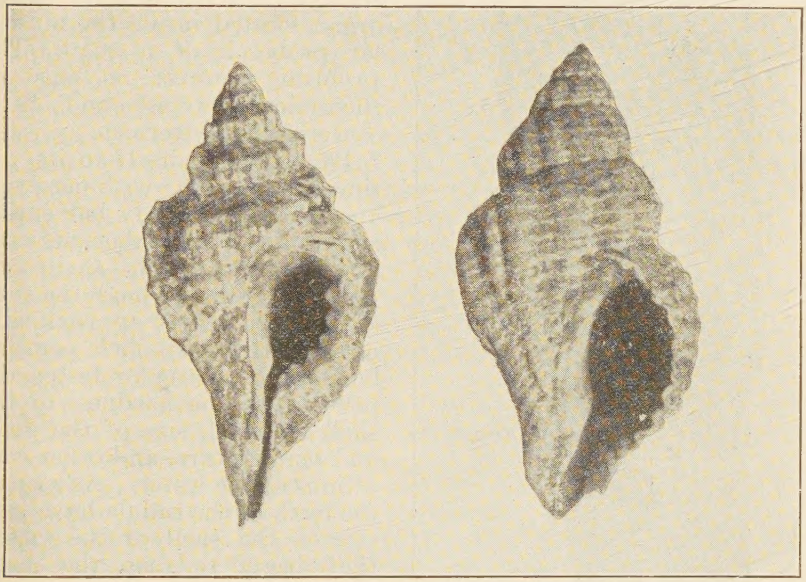

FIGURE 1.—Common oyster drills, *Urosalpinx cinerea* Say (right) and *Eupleura caudata* Say (left). (Enlarged twice.)

pinx has an aperture with a short siphonal canal (fig. 1), while in the *Eupleura* shell the canal is long. In most localities the adult *Urosalpinx* averages slightly over 1 inch long and about three-fifths of an inch wide except at Seaside, Va., where specimens as large as 2⅜ inches long and seven-eighths of an inch wide are very common. The adult *Eupleura* averages from ¾ to 1¾ inches in length and from ⅜ to ⅞ inch in width.

METHOD OF ATTACKING PREY

The oyster drill derives its name from its ability to bore circular holes in the shells of oysters, mussels, and other mollusks which constitute its prey. For this purpose it is equipped with a special rasping organ, the radula (fig. 2) which can best be compared to a ribbon-like film beset with thousands of minute chitinous teeth arranged in

rows. The radula, borne on a flexible membrane, is located in the proboscis of the animal.

The exact mode of operation of the radula is still a subject of arguments among the zoologists. Up to the present time two principal explanations have been brought forward: (1) The radula itself is more or less stationary, its rasping action being accomplished by the movement of the cartilages upon which it rests. The movements of the organ are comparable to the licking motion of a cat's tongue. (2) The radula, borne on a flexible membrane, rotates over cartilages like a belt over a pulley. Lack of agreement on this point is understandable if one realizes the difficulties encountered in observing the action of a very small organ located inside the muscular proboscis of a snail. The problem, however, is only of theoretical interest and little concerns the oystermen.

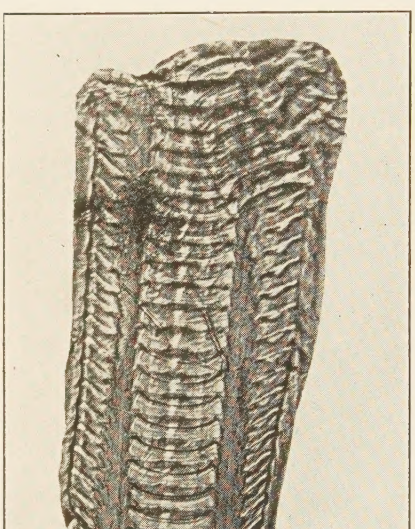

FIGURE 2.—Photomicrograph of a piece of radula of *Urosalpinx cinerea*. (Magnified 103 times.)

By attaching itself to its victim and by boring with perseverance the drill slowly but surely accomplishes the laborious task of penetrating the shell. The rate of drilling through the shell of an adult oyster approximates one-fiftieth of an inch per day but may be slower or faster, depending on the hardness of the shell material, size of the drill and temperature, and other conditions of the water. As soon as the teeth of the radula have penetrated the shell of the victim they begin to rasp the meat which is sucked by the proboscis. The wound inflicted soon causes the oyster to relax the muscle thereby permitting the shell to open and expose the animal within to the depredations of crabs and fishes, which consume the victim even before the drills are able to finish it. It has been observed in the laboratory that one drill devoured about four-tenths of a cubic inch of oyster meat in 24 hours.

LOCOMOTION

Like the majority of other snails, drills are provided with a highly contractile muscular foot which is used for creeping. Its lower surface is covered by cilia, minute hairlike structures, the beating movements of which propel the animal. Adhesion of the animal to the substratum depends entirely on the secretion of slime by its foot

Creeping is slow and is influenced by the character of the ground and temperature. It has been observed in the laboratory that the animal may move either on a horizontal or a vertical surface at the rate of about 1 inch per minute.

Since various conditions of the environment, as, for instance, temperature of the water, its salinity, the character of the substratum over which the animal travels and the intensity of light, exercise their influence on the activities of the drill, its movements are necessarily extremely variable. The currents also exert an interesting effect. In running sea water the drills orient themselves, pointing the siphon upstream and the apex of the shell downstream, and move against the current. The stronger the current the quicker the drill will turn itself against it, although the rate of creeping is not influenced by the velocity of the water passed over the animal. Thus, one should expect that under natural conditions, barring other obstacles, the drill will have a tendency to move against the current. This fact should be taken into consideration when selecting bottoms for planting oysters.

That direct sunlight has a pronounced effect on drills has been demonstrated in this laboratory experiment (Sizer, 1936) : The apparatus was a glass tank, the walls of which were painted black except for the lower half of one side, and the top was covered with a tightly fitting lid. In this apparatus drills were lined up at the center of the bottom, and the tank set up on the roof exposed to direct sunlight. The temperature of the water was kept under 77° F. About 70 percent of the drills studied under these conditions moved away from the source of light; the remaining 30 percent showed no definite reaction. When the light intensity was reduced by placing a sheet of paper in front of the tank the drills had a tendency to move toward the source of light. These results of the laboratory experiments are confirmed by certain field observations. In shallow water (1 to 4 feet deep) on bright sunny days, drills were observed to be attached to the under side of oyster clusters. On cloudy days they were often found on the top of the clusters. Likewise, in the murky waters of Delaware Bay at depths of about 15 feet there are usually more drills on the top of an oyster cluster than on the lower part of it. One should consider, however, that under natural conditions all the factors of the environment, temperature, salinity, currents, character of the bottom, chemical composition of the water, light, etc., act upon the animal. Its behavior is therefore determined by the combined and sometimes antagonistic effects of these factors and cannot be attributed to a single cause.

The concentration of salt (salinity) in the sea water, which in the inshore waters fluctuates widely, depending on the amount of precipitation and river discharge, exerts a very strong effect on the movements of drills. The *Urosalpinx* from Delaware Bay is inactive at salinities below 15 or above 29 parts per thousand and moves with greatest velocity near the higher salinity limit, as shown by repeated laboratory experiments as well as field observations.

One of the most striking habits of the drill, the one upon which the method of trapping this animal is partially based, is the tendency to creep upward. It manifests itself especially during the breeding season when the female crawls up to higher levels to lay eggs. That

this tendency is not due to temperature, light, salinity, oxygen content, or any stimulus can be demonstrated by a simple experiment. If an animal is allowed to adhere to a glass plate, the plate raised vertically and then turned around as a wheel on its hub, the drill will always turn so that the shell apex points down and the siphon up, and begin to creep upward. It will act in a similar manner in the darkness and in water saturated with oxygen. This habit permits the drill to deposit its eggs above the bottom where the developing embryos and newly hatched animals will find more favorable conditions than on the bottom. During the winter the drill returns to the bottom where it hibernates just below the surface of the mud or sand until the rise of temperature to about 40° F. again initiates its activity.

MIGRATIONS

Wide distribution of the drill raises the question whether the animal is capable of moving over long distances and, if so, what induces its rambling. Obviously a correct answer to this question provides a key to the control methods. First attempts to obtain a solution to this problem were made several years ago by Federighi, who conducted field experiments at Norfolk (Hampton Roads), Va., and at Beaufort, N. C. He attached small celluloid tags by wiring them to the outer lip of the shell, and released the animals on the natural oyster bottoms in a designated area in shallow water. After 1 month it was found that tagged drills had not moved over 10 to 15 feet from the original point of planting. Even those planted about 200 feet away from the oyster bed on hard bottom devoid of food did not move toward the oysters. It was concluded from the observations that the movements of *Urosalpinx cinerea* are limited and independent of the presence of a food supply. This was substantiated by further similar observations. Consequently, for some years it was believed that the oyster drill did not travel any appreciable distance.

Records of the recent investigations in Delaware Bay tell a different story. In these field observations experimental drills were marked by dipping the spire of their shells into a bright colored quick-drying lacquer which persists for several months, enabling the easy identification of the animals. The drills were released in large areas enclosed by screens, and on different types of bottom devoid of oysters and shells—hard, soft, and loose sand mixed with mud at depths varying from 15 feet to low water mark. At certain distances from the planted drills cages baited either with young oysters or filled with shells were placed. Each day the cages were examined and the number of lacquered drills counted. Every examination showed that more marked drills had migrated from the place of liberation to the cages containing live bait than to those containing dead shells. It follows from the results of these experiments conducted over a period of several months that, contrary to previous ideas, the drills' migratory activities are influenced by the position of food and they move toward it at the rate of at least 150 feet in 48 hours, a faster rate than was heretofore recorded.

Since the exact path of drills could not be observed, the distances given here represent the shortest line between the place where the drills were released and the position of the bait. In some experi-

ments, however, the path of the drills appeared to be influenced to some extent by the direction of currents, the animals moving against the latter. In general, however, their migration was influenced by the position of the food supply. In any case they were able to crawl over all types of bottom used. There now seems to be little doubt that in the search for food *Urosalpinx* is able to travel a considerable distance, and that its places of concentration may be correlated with the presence of an abundant supply of oysters or other natural food.

Migration studies in Delaware Bay also indicate that *Urosalpinx* can travel both faster and farther than *Eupleura*. In each case where there was an abundance of food the latter did not appear to move so far or so quickly.

Migration is not the only explanation of drill distribution. Another agency, and probably the principal one, is the oysterman himself, who by transplanting seed oysters infested with drills or drill spawn, inadvertently assists in spreading this pest. The following example suffices to illustrate this point. One planter was known to move 60,000 bushels of oysters from a very badly infested area having a salinity so low that the drills were not doing much damage. Without screening or even forking the oysters he transplanted them to another area not so heavily infested but having a more favorable salinity. In 1 year the new bed was almost a total loss.

EFFECT OF SALINITY ON DISTRIBUTION

Fortunately nature provides a powerful bar to the inroads of drills. Since a greater part of the oyster bottoms is located near the mouths of rivers, the drop in salinity at high stages of the rivers is often sufficient to destroy the drills or check their migration. The conditions in Delaware Bay illustrate this very clearly. At the mouth of the Maurice River, where the salinity for a large portion of the year remains below 15 parts per thousand, there are no drills. The same condition obtains up the bay toward the Delaware River where natural reefs are found. Oyster bottoms in all other sections of the bay with higher salinity are badly infested. During the summer of 1935 owing to an abnormally low precipitation the salinity in the upper part of the bay was higher than usual and previously uninfested reefs were invaded by drills. Furthermore, records show a positive correlation between drill distribution in this part of Delaware Bay and the seasonal rise and fall of salinity.

Laboratory experiments have shown that a salinity of about 11 parts per thousand kills the drills, and that this dilution of sea water constitutes a natural barrier to the distribution of the pest. The fresher the sea water the quicker is its toxic action on drills. In a salinity of 5 parts per thousand the drills are killed in 4 days; in that of 10 parts per thousand they are killed in 7 days.

The ability of the drill to withstand brackish water depends a great deal, however, upon the salinity of the environment in which the animal has lived previously. For instance, Federighi has shown that drills from localities near Norfolk Point, Va., where salinities ranged from 15 to 20 parts per thousand, were killed in water of salinity 11.7 to 12.5 parts per thousand. On the other hand, drills from Beaufort, N. C., which live in a salinity of about 30 parts per thousand were killed by salinities of 15.6 to 17.6 parts per thousand.

Although there is undoubtedly some adaptation to changes in salinity one can conclude that in general salinities of less than 11 parts per thousand constitute a barrier to the distribution of drills in the coastal waters.

FOOD AND FEEDING

The drill eats a variety of mollusks such as oysters, mussels, scallops, clams, slipper shells; also chitons, barnacles, and small crabs. Drills have also been observed to feed on their own kind, even in the midst of a plentiful supply of oysters.

Its ravages on the oyster bottoms have been found to vary in different localities. In North Carolina waters, it is reported that a single *Urosalpinx* destroys from 30 to 200 oysters, depending upon their size, in a season. In New Jersey recent studies show that one drill may devour on the average 0.34 adult oysters per week over a 9 week period in the summer months, and that over 300 spat can be killed by one snail in a single season. A single oyster may become the victim of several drills at the same time, all continuing boring activities even though one has already successfully penetrated the oyster's shell and is in the act of devouring its enclosed tissue. In most cases, however, as soon as the oyster is gaping as the result of the perforation and injury made by one drill, other drills are attracted to it and devour its meat. In the laboratory at Woods Hole one snail was observed to bore into a 5-centimeter oyster and to have consumed it alone.

From many observations in New Jersey waters it appears that the feed-activities are influenced by changes in temperature. During the 9 weeks of the investigation the temperature rose from 66.2° F. at the beginning of the study in June (1935) to a peak of 82.4° late in July, and from that point dropped in 3 weeks to 76.8° F. The number of oysters drilled and destroyed each week in the experimental baskets placed at different stations increased with the temperature from an average of 5 at the beginning to 8 during the weeks of high temperature and down to 6 at the close of the experiment in August (1935). According to Federighi (1931) drills at Hampton Roads begin to feed when the temperature rises above 59° F. and at its drop to 50° F. the feeding immediately ceases, the animal becoming inactive. Similar observations in Delaware Bay indicate that drilling completely ceases at 49.1° F. Laboratory observations both at Hampton Roads and Beaufort demonstrated that a sudden drop in temperature even when it had been above 68° F., was accompanied by complete cessation of feeding, the drill moving away from its victim to attach itself elsewhere in the aquarium.

Feeding activities have also been found to be affected by the salinity of the water. Drills cease boring when the salinity falls below a point estimated approximately between 10 and 12 parts per thousand.

In order to learn the food preferences of drills, experiments were carried out at Woods Hole, Mass., over a period of approximately 3 months (1935). It was found that drills put into a large aquarium containing young and old oysters, mussels, periwinkles, scallops, slipper shells, claims, and jingle shells, ate all except the jingle shell with little selectivity. But when to this medley of animals a rock of live barnacles was added, the *Urosalpinx* in a very short time

covered it completely, and soon destroyed all the barnacles. The addition of still another fresh barnacle-covered rock proved an even greater attraction. Actual observation of a barnacle to which a drill was attached showed that the victim's tissues had been partially sucked out. Examination of the barnacle under the microscope, however, revealed no perforations in its shell. It is evident, then, that drills show a decided preference for barnacles over all other food animals studied. This preference may be due to the accessibility and lack of protection of the edible parts of the barnacle.

Field experiments in Delaware Bay showed that young mussels, *Mytilus edulis*, present greater attraction to drills than young oysters. Two cages were set out in the bay with equal numbers of young oysters and mussels. An equal number of drills was placed in each cage which were examined at regular intervals. In one cage it was found that all the mussels were destroyed before any oysters were attacked. In the other cage 75 percent of the mussels were drilled and eaten before the oysters were attacked. Further experiments in trapping drills showed the mussel to be twice as efficient in attracting drills than are oysters when both are used for bait.

Of all the foods offered to drills in the course of food preference experiments, the jingle shell remained untouched. Even drills starved for almost 3 months spurned this mollusk. Yet when these same drills were offered a shucked specimen, they consumed it within 17 hours. It is evident then, that the shell of this mollusk proves a barrier to drills.

It has often been observed that drills prefer young oysters to adults when both are available. This fact has led previous investigators to conclude that this selection is determined by the thickness of the shell. But in the present study it has been found that the drill is not able to detect the thinnest shelled oysters or even the weakest spot of a single oyster. In many cases, among shells of different thickness, drills sometimes attacked thick-shelled oysters first; and at times even drilled the thickest part of the shells. Nevertheless, preference for young oysters is fully corroborated by experiments with drill traps, in which as high as 80 percent of the new spat set on the 1-year-old specimens used as bait were quickly destroyed. When in the same locality both 2- and 3-year-old oysters were available, more drills were found ravaging the younger oysters than the older ones. All the investigations concerning the food and feeding habits of the drill demonstrate that it is primarily an enemy of the young oysters, a far greater proportion of seed oysters and spat than adults being destroyed annually.

From the results of the observations of feeding habits a conclusion may be drawn that a well-developed chemical sensitivity or an organ of smell enables the drill to detect the most desirable food and to be lead to it. This is probably accomplished through a special organ, the osphradium, intimately connected with the breathing organ and placed near its base. It is of interest that live young oysters are attacked more readily than their shucked meats, indicating that possibly some sort of excretion of the living organism attracts the drill rather than the meat itself.

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TEMPERATURE AND ACTIVITIES OF THE DRILL

Laboratory experiments in which the drills were kept under continuous observations in tanks and also field observations showed that the activities of the oyster drill are greatly influenced by temperature. With the advent of cold weather, drilling and feeding cease at about 50° F. Total inactivity and complete cessation of crawling occur when the temperature reaches a point between 36.0° and 30.2° F., the drills remaining in a state of hibernation until the onset of warm weather. They begin to move again in the spring when the temperature of the water reaches 40° F., but start feeding only after the temperature has risen above 50° F. This occurs about the middle of March in Delaware Bay, but is earlier in States south of New Jersey and later in New England waters. During extreme low temperatures from 26° to 35° F., the drills either remain dormant on the surface of the mud or burrow into it enough to cover the shell. In the latter case they are usually attached to the sides of oysters, old shells, stones, etc., and are oriented so that the tip of the anterior canal projects slightly above the surrounding bottom. They burrow in this way also on tidal flats during midsummer when subjected to high temperatures. No evidence was obtained that drills seek and congregate in cavities of empty shells for protection during cold weather.

FIGURE 3.—Egg cases of common drills, *Urosalpinx cinerea* (left) and *Eupleura caudata* (right).

BREEDING

With the onset of warm weather and resumption of feeding, drills begin to deposit their egg cases. They are cream-colored, vase-shaped leathery capsules, approximately one-fourth inch long (fig. 3), and are attached by means of a strong stemlike base to rocks, shells, or other solid materials elevated above the bottom. In Delaware Bay deposition of egg capsules begins after the water temperature has reached 57° F., viz, about the first week of April; and continues until late November. The recent investigations on *Urosalpinx* in Chincoteague, Va., showed a more or less continuous spawning over a period of 7½ months, from June to January, with a climax during June and July. In Cape Cod waters the drills were observed to deposit eggs from at least the end of June (the beginning of observations) through July and the first half of August. A second, less prolific period of spawning was noticed during the second half of September.

In drills the sexes are separate. Although copulation undoubtedly occurs, it never was observed in the laboratory nor were the copu-

lating drills collected in the field. Ripe females cease feeding and invariably creep to higher levels to spawn, thus keeping the eggs from being buried in the mud and consequently suffocated. If disturbed while spawning the female may cease depositing eggs and creep away and return in a few days to resume spawning.

Preparatory to the laying of eggs the surface upon which the cases are to be attached is carefully scraped and cleaned by the use of the radula. Deposition of eggs may last for several days, sometimes as long as 7. According to Federighi's observations at Hampton Roads, Va., each female *Urosalpinx* lays an average of 28 to 29 egg cases at the approximate rate of 4 per day. The capsules contain from 3 to 20 eggs, averaging 9 eggs per case. In Delaware Bay it was found that one *Urosalpinx* female may deposit as many as 50 capsules which are grouped in clusters. The number of eggs in 1,297 cases examined varied from 0 to 20, and averaged 8. *Eupleura* is more prolific than *Urosalpinx*, the limits for the number of eggs of this species per case varying from 8 to 42 (Haskin, 1936). On the average there were 22 *Eupleura* eggs per case.

TABLE 1.—*Relation between type of food eaten and fertility*

Tank no.	Type of food	Period of spawning		Range of temperature, °F.	Number cases laid	Second spawning[1] start	Temperature, °F	Number of cases
		Start	End					
1	Barnacles	June 25	July 15	66–73	175	Sept. 15	66	75
2	Seed oysters	June 22	Aug. 12	66–73	130	None		None
3	Marsh mussel	June 29	Aug. 10	68–73	90	Sept. 14	66	5
4	Seed oysters	June 25	July 9	66–71	80	None		
5	do	do	July 7	66–70	50	Sept. 14	66	25
6	Edible mussel	June 29	July 17	68–71	50	None		
7	Scallops	June 22	July 28	71–72	40	None		
8	Jingle shells	June 26	June 30	68–69	15	None		
9	No food	June 25	do	68–69	11	None		

[1] The duration of the second spawning could not be determined because the closing of the laboratory necessitated discontinuing the experiments.

In order to study the relation between the quality of food which drills eat and the fertility, the following experiments were made at Woods Hole, Mass., during the summer of 1935. Lots of 10 drills each were kept in tanks supplied with running sea water and containing various types of food animals. One tank contained no food. At the conclusion of the season, considerable variation in the number of egg cases deposited was found among these tanks, as shown in table 1. It is evident, then, that the fertility of drills is correlated with the quantity and quality of their food.

PERIOD OF DEVELOPMENT

The egg capsules of both *Urosalpinx* and *Eupleura* are flattened and are provided with a detachable hinged cap through which the young embryos may escape (fig. 3). The capsules of *Urosalpinx* are more or less rounded or elliptical at the top; those of *Eupleura* are notched.

In Delaware Bay the period of development of *Urosalpinx*, i. e., the time from spawning to hatching varies from 21 to 53 days.

Experiments with a number of inorganic solutions, organic salts, and dyes showed that the walls or cap of the egg case are permeable

to these substances. These tests suggest that the egg capsule provides better protection against larger animals and possibly microorganisms than against the chemical changes which may occur in the sea water. A study of this problem is being continued.

METHODS OF CONTROL

The control of the drill obviously resolves itself into two distinct problems: First, the prevention of migration and its consequent spread over new areas; second, its removal from the infested bottom and its destruction. Various methods used in oyster-culture practice can be roughly classed into two groups: (1) Mechanical, in which various mechanical devices or procedures are applied for the removal of the snails from bottoms or their separation from the oyster shells, and (2) biological, in which the knowledge of the life history of the animal and its habits is utilized for trapping the drill.

MECHANICAL METHODS

It has been learned from previous investigations of the Bureau and from experience in shipping the American oyster to the Pacific coast and to Europe that the practice of relaying infested oysters is greatly responsible for the wide distribution of the drill. There is no doubt that further spread of this pest can easily be checked if the oyster growers are careful not to plant infested oysters in noninfested areas. Before starting planting operations, as many of the drills as possible should be removed both from the bottoms and from the stock to be transplanted. This can be achieved by various methods described below, the selection of which must be governed by local conditions.

FORKING

After the infested oysters have been put aboard an oyster boat, they should be thrown onto the new bed, not with shovels, but with pitchforks like those used by farmers. Before throwing them overboard a forkful of oysters should be dropped on the deck and taken up again a couple of times so as to shake off the drills. Later they can be destroyed. The method is simple and inexpensive, adding but slightly to the time of planting.

SCREENING

By this method drill infested oysters after being dredged are allowed to remain for several hours on deck, then are shovelled and thrown against a screen made of 1-inch mesh, double weight chicken wire. Drills loosened by the exposure to air easily fall through the screen and are destroyed. This method is more efficient than forking. On the larger dredge boats a heavy 1-inch mesh grating behind the dredge roller to catch the load as it is dumped will be more serviceable. Some of these are in use on boats operating in Delaware Bay.

FLOATING

Since drills are less resistant to fresh-water than oysters, they can be removed from oysters to which they are stuck by placing the oysters to be planted in large cars or floats and anchoring them

for about 10 days in brackish water which is fresh enough to kill the drills, but salt enough to leave the oysters unharmed. Inasmuch as the survival of the drill in brackish water depends to a great extent on the concentration of salt in the water in which it had previously lived the exact salinity which would kill the drill should be determined for each locality separately. The method, although expensive, is very efficient. It has the added advantage of killing small newly hatched drills which usually escape when mechanical methods are used. It requires the use of floats, however, and the ability of the oystermen to determine the salinity of the water and make a preliminary test on drills.

DREDGING

For catching large quantities of drills over the oyster bottoms a drill dredge can be used. Earlier attempts to use the dredge for clearing the drill-infested bottoms of Long Island Sound were made by Capt. T. Thomas (Moore, 1897, p. 317) who devised an implement consisting of a wire cage open in front and fitted with an inclined screen. When the dredge is dragged over the oyster bed the oysters are picked up by the blade, moved up over the inclined plane, and the drills automatically screened fall into the cage below while the oysters pass over and fall back onto the bottom. The efficiency of this dredge, however, is not very great.

Similar types of drill dredges have been tried by the oystermen in Delaware Bay, Chesapeake Bay, and Pamlico Sound with various results. In the course of the present investigation the following modifications of the old type have been developed (fig. 4, A–D). A wedge-shaped galvanized iron pan with an inclined grating is attached to the frame of an oyster dredge, the chain bag of which has been removed. The pan is essentially a trash sifter that separates the drills and debris from the oysters.

The dimensions of the pan depend on the size of the dredge frame. For the 42-inch dredge, the one most generally used in Delaware Bay, the pan can be 40 inches wide, 30 inches deep, and 12 inches high. The sides and bottom are made of heavy-gage galvanized iron, and the back and top of a grating composed of half round iron strips spot-welded together to form a 1-inch mesh network. The back and part of the top are lined with ⅛-inch mesh galvanized rat wire to prevent small drills from being washed through and liberated. Strips of strap iron 1-inch wide and ¼-inch thick are run across the bottom and up the back to act as runners to keep the bottom of the pan off the bottom of the bay. At either end of the runner strips, the iron is bent to form channels for the hinge bar of the top, and channels for the attachment bar for the dredge (fig. 4 C). The sides and bottom should be well perforated with ⅛- to ⅛-inch holes to allow free passage of water to insure against clogging with mud and sand.

A light chain is attached to the back of the pan and brought forward to the dredge frame to adjust the slope of the pan and digging bar of the dredge. A few trial drags with the drill dredge will be enough to show the experienced oysterman the proper pitch for the pan.

The dredge used in the tests by the Bureau of Fisheries had a 42-inch scraper bar attached to a medium-weight frame. The equipment including dredge and drill weighed 150 pounds and could be handled easily by two men. A small power boat with light winding gear could drag a dredge economically over a small area of a few acres; but on larger grounds the regular dredging schooners equipped

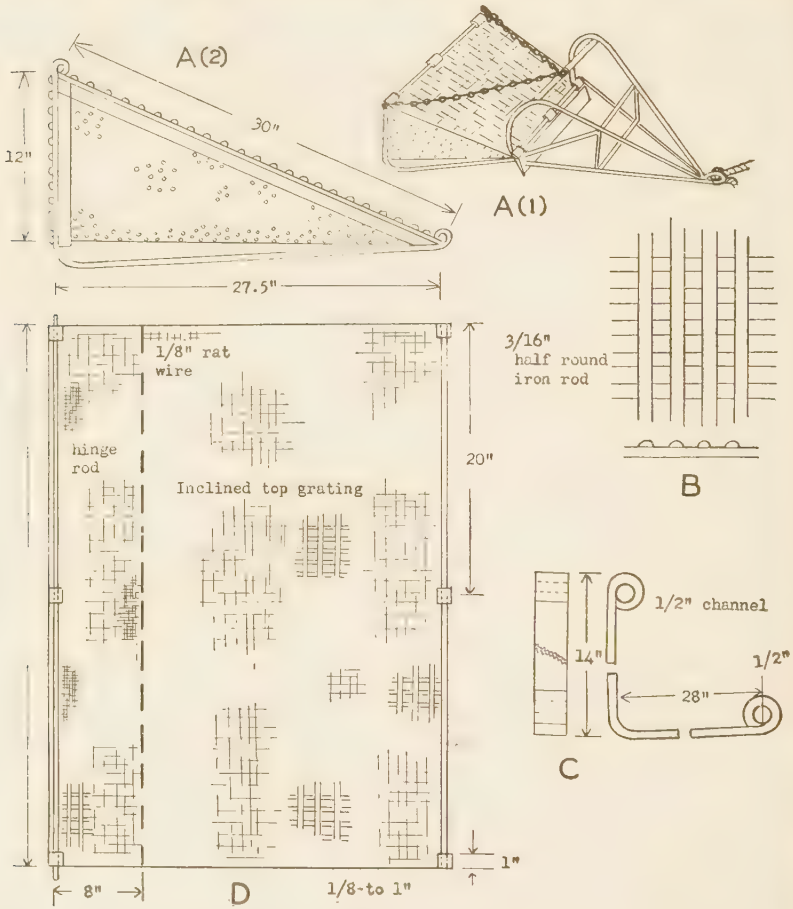

FIGURE 4.—Drill dredge and details of its construction. *A* (1), drill dredge and pan; *A* (2), Construction of sheet metal side; *B*, grating construction; *C*, hinges and runner strips; *D*, details of drill pan construction.

with two drill dredges would be most efficient for this work. A crew of two men would be adequate if the dredges were pulled alternately.

The type of blade to be used, whether scraper or a toothed bar, depends upon the hardness of the bottom to be worked.

The dredge is handled in the same manner as an oyster dredge with the exception that the pan must be lifted off the bottom by an adjusting line or chain attached to the frame. An oysterman who knows how to "feel" the dredge's action on the bottom can easily make this adjustment.

The efficiency of the drill dredge can be judged by the results of the operations on a 15-acre area of oyster bottom in Delaware Bay. The number of drills collected during 9 consecutive hours of dredging, shows a gradual decrease in the number of drill caught. The laboratory boat used in this test was equipped with only one dredge. An oyster boat equipped with two dredges would probably double this catch and materially reduce the drill population.

Hours of dredging:	*Drills caught*
First	3,355
Second	1,706
Third	2,165
Fourth	2,155
Fifth	2,543
Sixth	1,825
Seventh	1,988
Eighth	1,687
Ninth	1,858

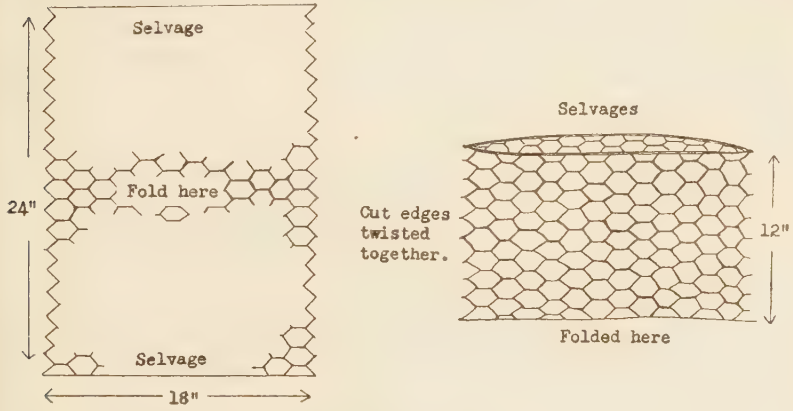

FIGURE 5.—Construction of chicken wire bag trap.

BIOLOGICAL METHODS

TRAPPING

Familiarity with the life history and habits of the drill permits the development of biological methods of control. Observations some years ago of the snail's tendency to creep upward suggested the use of small concrete pillars, 10 inches in diameter and 12 inches high, as a means of eliminating drills (Federighi, 1930). These pillars provide surfaces higher than the surrounding area and act as traps for the snails congregating upon them. They can be lifted from the water, cleaned of drills and replaced.

The trap idea was further developed by J. R. Nelson (1931) who suggested the use of a bag 12 by 18 inches, made of no. 20 chicken wire of 1-inch mesh and filled with seed oysters. After being left for several days in the water the bag is lifted and the drills collected in it are shaken out. Such traps were planted on a suitable line about 20 feet apart stretched across the oyster bottom at a depth of 15 feet. Large scale experiments with Nelson's traps were undertaken in the present study with a view of investigating their practicability, improving their construction, testing various baits, and learning the most efficient method of setting the lines of traps.

CONSTRUCTION OF TRAPS

CHICKEN WIRE BAG TRAP

For the traps used in these experiments galvanized chicken wire 18 gage, 1-inch mesh, 24 inches wide is used. To construct the bag, an 18-inch strip of this wire is folded to form a bag 12 inches high and 18 inches long. The selvage edge must come at the open end of the bag (fig. 5). The edges forming the sides are twisted together to complete the bag. All rough ends must be folded in to make handling easier.

GALVANIZED IRON TRAP

The galvanized iron trap (fig. 6) differs from the wire bag trap in that the drills enter at the ends through special openings covered with hinged metal strips which swing inward only and prevent their escape. In the center of this trap seed oysters are kept in a small box

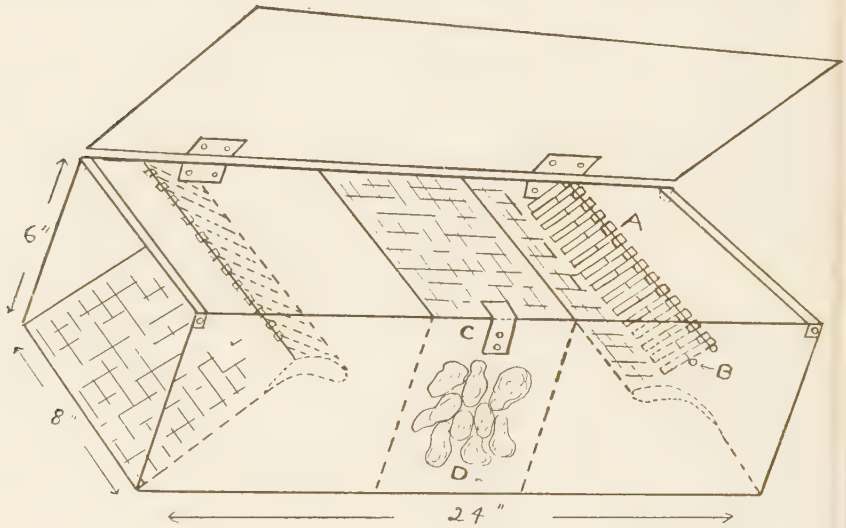

FIGURE 6.—Galvanized iron drill trap. *A*, ¼-inch strips separated by ¼-inch beads or washers; *B*, light rod to hold strips ½-inch above lead-in wire; *C*, catch; *D*, seed in removable wire box of ¼-inch hardware cloth.

made of ¼-inch hardware cloth which protects them from destruction by the trapped drills. The principal advantage of this kind of trap is that it may be left on oyster beds for a month or more unattended. It should be placed on the bottom so that the long axis of the trap is parallel to the direction of the flood and ebb currents.

BAITING

Young oysters, 1 to 2 years old in clusters make the most serviceable bait for all types of traps. Where mussels and barnacles are to be found growing together with the oysters they should be included. The chicken-wire traps will hold a peck of bait, which should be loose enough to allow some freedom for shaking out the attached drills when the traps are tended. Rebaiting with fresh material will occasionally be necessary when too many of the seed oysters are killed

by drills. If the traps are tended once a week the mortality among the seed will be low. Galvanized iron traps do not need rebaiting.

ARRANGEMENT OF TRAPS

In the operations in Delaware Bay wire bag traps were attached to short snoods 6 to 12 feet long spliced onto the main line at intervals of about 9 feet, 25 feet being left free at both ends of the main line for tying to stakes driven into the bottom. (See fig. 7.) Fifty trap on one line of 500 feet make an adaptable unit which can be lengthened if necessary by joining to one or more similar lines. The rope was impregnated with copper oleate in order to withstand the destructive action of seawater and marine organisms. The size recommended for the main line is ½- or ⅜-inch diameter, 3-strand, medium laid manila; the snoods or short lines can be of the same structure but ⅜- or ¼-inch in diameter.

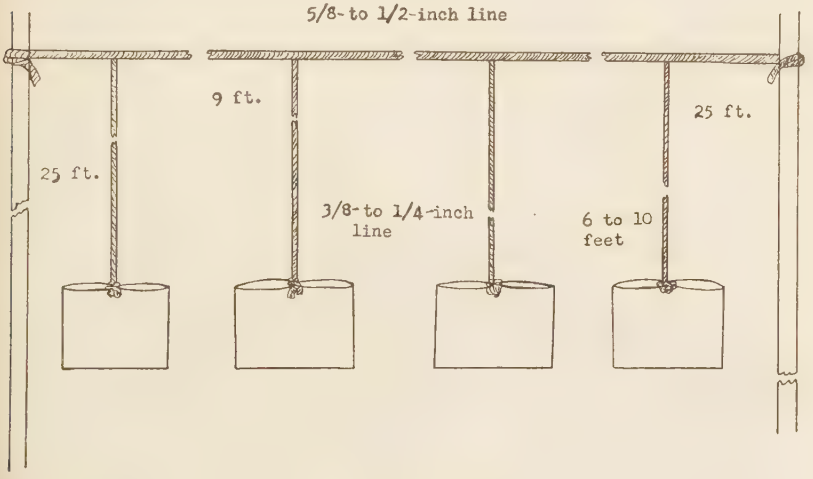

FIGURE 7.—Arrangement of traps on line and attachment to stakes. Fifty traps are placed on one line of 500 ft. which is attached at both ends to stakes.

In Chincoteague it was found more convenient to use a set of 25 traps attached to a 250-foot line made of ⅜-inch steam-tarred or copper-treated manila rope. The traps were spaced at 10-foot intervals and fastened to the main lines with a 4-foot piece of ¼-inch steam-tarred rope. Good results were also obtained by attaching the traps directly to the main line. One end of each trap line was tied, just above the surface of the water, to a heavy stake 3 to 5 inches in diameter, which was well secured in the bottom. The first trap was generally placed near the stake and the line allowed to settle to the bottom so as to prevent possible entanglement by passing boats. On soft bottoms the line may quickly rot, however, in which case it is advisable to use a stake at each end and tighten the rope sufficiently to keep it clear of the mud.

Another method which can be used is to eliminate the line altogether and instead, fasten the traps individually or in pairs to stakes or buoys with a few feet of light rope of flexible wire. This is satis-

factory when the drills are not very abundant and when a small number of traps is scattered over a comparatively large area.

SETTING

In Delaware Bay the traps were set out in a "trot" line (fig. 8) with the ends of the long line secured to stakes to keep them in place. Several methods of arranging these on a ground have been found efficient. The first method is to "zigzag" a series of lines across the section to be trapped (fig. 9). This arrangement covers a maximum of territory and tends to catch drills migrating in all directions. A second method more economical but less efficient is to place a straight line of traps at one end of a ground and periodically move it forward

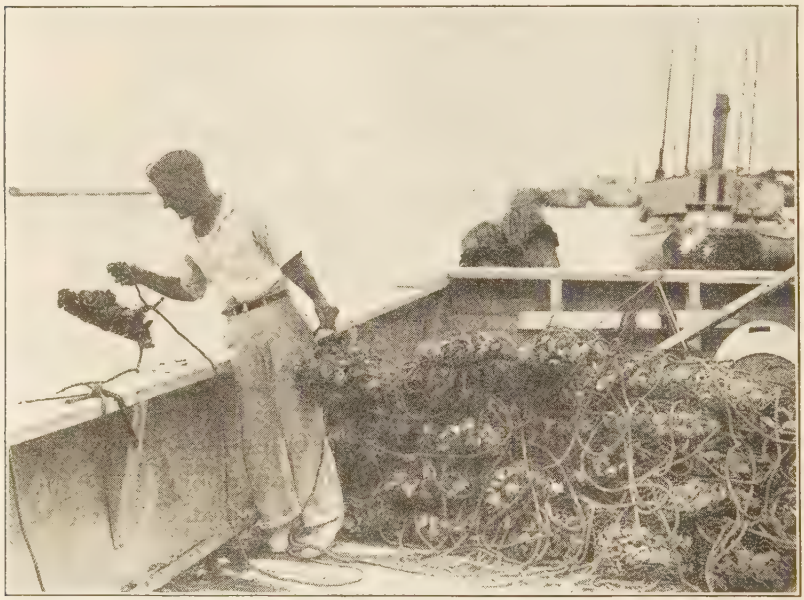

FIGURE 8.—Laying a line of wire bag traps in Delaware Bay.

until the entire area has been trapped. During the whole of the warm-weather period, while drills are active, an area can be gone over several times in this way.

A third method that can be used is to surround the ground with a circle of traps and place in the middle a long line which can be moved about to catch those drills within the ground and to pick up stragglers which may have entered the circle. Surrounding the oyster ground with traps is a means of preventing reinfestation of a cleaned section, and furnishes a reasonable protection of planted seed and new set (fig. 11).

The most successful procedure at Chincoteague, however, was to anchor one end of a 250-foot line (25 traps) in the center of each 4-acre unit and shift the position of the line about 45° at intervals as shown in figure 12. In this way a circular area of bottom having a diameter of 500 feet is covered by 8 successive fishings after which the procedure is repeated until very few drills are caught.

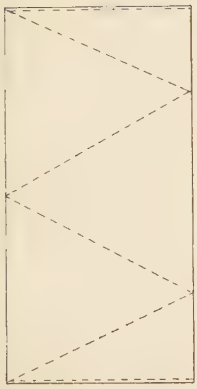

Fig. 9

Fig. 10

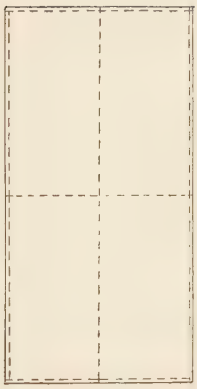

Fig. 11

FIGURE 9.—Zig-zag arrangement of trap lines. Six lines, 50 traps in a line.
FIGURE 10.—Parallel arrangement of trap lines. Five lines, 50 traps in a line.
FIGURE 11..—Arrangement of trap lines on an oyster ground of approximately 12 acres. Each is 500 feet long. Nine lines, 50 traps in a line.

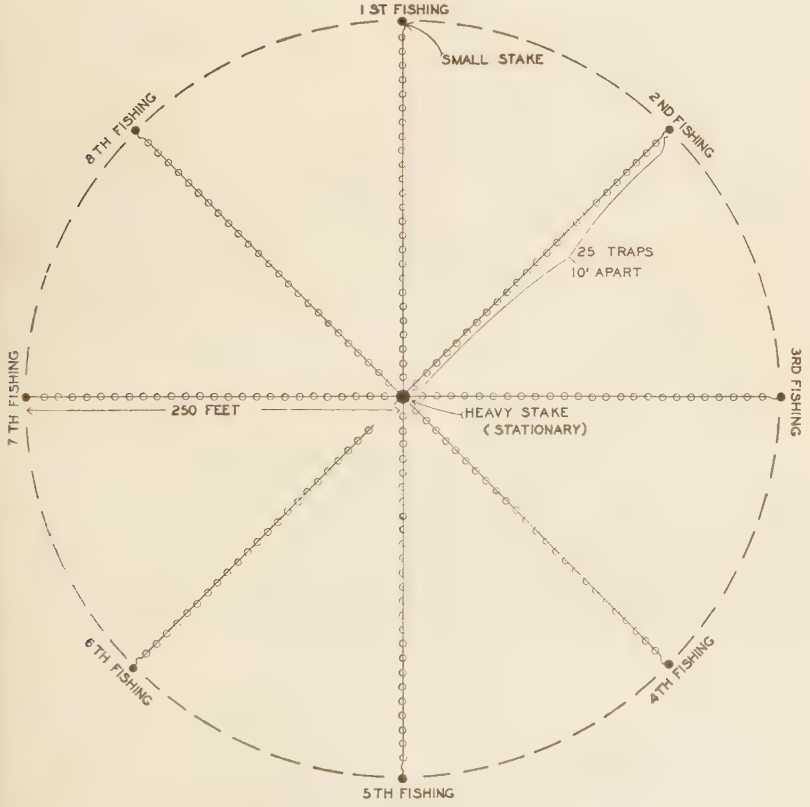

FIGURE 12.—Radial trapping with single line of traps.

One end of the trap line is tied to a heavy stake at the center of the circle, and the other end to a light stake on the outer edge.

In fishing, the line is untied from the light stake, the traps taken into the boat one by one, and the drills shaken out. When the center stake is reached and the last trap cleaned, the line is reset at an angle of 45° to the previous position and its outer end secured. In experiments with this radial type of trapping 83 percent of the total number of drills caught were obtained on the first complete circuit (8 fishings), 14 percent on the second, and 3 percent on the third. The results of individual catches on the radial lines indicate that drills are caught near the center of the circle where the area covered per trap is proportionally less than at the periphery. In these experiments the lines were fished every 4 days for it was found that practically as many drills were caught during this interval as when the traps were fished every 7 days. Therefore by this procedure it is possible with 1 line of 25 traps to remove virtually all of the drills from 4 acres of bottom in approximately 3 months.

After a bed has been cleaned of drills and is replanted with seed oysters, it is frequently advisable to protect this new stock against the invasion of drills from the surrounding bottoms. Such protection can be accomplished by leaving an unplanted zone, approximately 25 feet wide, around the oyster bed and placing on the outer edge of it a continuous line of traps at 5- to 8-foot intervals. During the warm weather the traps should be fished at least once a week and rebaited whenever necessary.

Experiments at Chincoteague have shown that the first requisite for the effective control of drills on an infested area is to prepare the grounds by removing seed or adult oysters from the bottom. In carrying out this operation a considerable number of pests will be caught, especially if tonging or dredging is done with a minimum of washing and shaking. In the absence of drill food trapping will be much more efficient than on ground abundantly populated with oysters. Certain beds which ordinarily are harvested during each oyster marketing season would be ready for trapping during the following spring and summer months. The advisability of trapping on previously harvested beds was clearly indicated by several experiments at Chincoteague, in which over 7,000 drills were caught in 8 weeks on cleaned bottom, as compared with only 300 drills for the same number of traps placed on oyster plantings.

According to the observations in the Chincoteague section the collection of drills by the radial method is more efficient than by other trapping procedures, requiring less expenditure of time, labor, and material. Representative trapping operations summarized by the following figures indicate the reduction in the number of drills caught during 3 consecutive months in 375 traps on the Eastern Shore of Virginia from July 1 to October 1, 1935:

	Drills taken
First month	26,228
Second month	13,052
Third month	6,000

The comparative efficiency of three different methods of setting traps can be judged by the following figures which show the number

of drills caught in 10 weeks by three different methods of trap-line operations, Eastern Shore, Va., 1935, 50 traps on each line.

Type of setting:	*Drills caught*
Lines stationary	4,094
Lines parallel	4,620
Lines moved radially	6,701

Where food is so abundant that drills cannot be lured by bait, trapping is impossible. Such places are found along the barnacle-covered rocky shores of New England. Eradication of drills from these localities is difficult and can be accomplished only by mechanical methods, i. e., hand picking during the summer and dredging in the winter.

COST OF OPERATION AND CONSTRUCTION OF TRAPS

The cost of trapping consists of the initial cost of the gear, and the operating expenses. In Delaware Bay, in order to effectively clean up 10 acres of oyster bottom, 250 to 450 traps are required, depending somewhat on the method used. The cost of the material for one line of traps is estimated as follows:

500 feet of copper oleate rope, ⅜–½ inch diameter (main lines)	$4.28	
500 feet of copper oleate rope, ⅜–¼ inch diameter (snoods)	3.42	
25 yards 18-gage, 1-inch mesh galvanized chicken wire	2.59	
Total cost of materials		$10.29
1½ days' labor to make 50 traps	6.00	
1 day's labor to make and splice 1 line (8 hours)	4.00	
Total cost for labor		10.00
Total cost per line of 50 traps		20.29

Operating expenses depend upon the number of traps set and the frequency with which they are tended. Under most conditions tending once each week should be sufficient. Two men in a rowboat can easily shake and reset 25 lines of traps in a 10-hour day including the travel time to and from the trapped area. Labor costs for tending and resetting traps depend on local wage scales. The union wage scale for watermen in Delaware Bay at the present time (1936) is $4 per day and board.

SPAWN COLLECTORS

During the period when spawning is most vigorous (May, June, July in Virginia; March, April, May in North Carolina; July and August in Massachusetts), it is possible to remove a considerable number of adult drills and egg capsules from the oyster beds by placing thereon numerous inexpensive devices, such as the following: (Fig. 13) (A) wire bags containing ½ to 1 peck of shells, (B) small blocks composed of shells cemented together with sand and portland cement, (C–D) frames of galvanized hardware cloth or metal lath plastered with a mixture of cement and sand, (E) conch shells wired together in groups of three or four, and (F) old tin cans of various sizes and shapes which may be used singly or wired together in small groups.

These devices should be attached to lines of ropes or wire, 100 to 150 feet long, and spaced at intervals of 2 to 10 feet according to the abundance of drills on each particular area. When so arranged they

can be taken up easily and quickly for the removal of the drills. They should be fished at least once a week during the spawning season, and put on shore to dry out for 3 or 4 days to kill the attached egg cases. This operation may be obviated however, by dipping the collectors in boiling water for 10 to 15 seconds, when they may be immediately replaced on the beds.

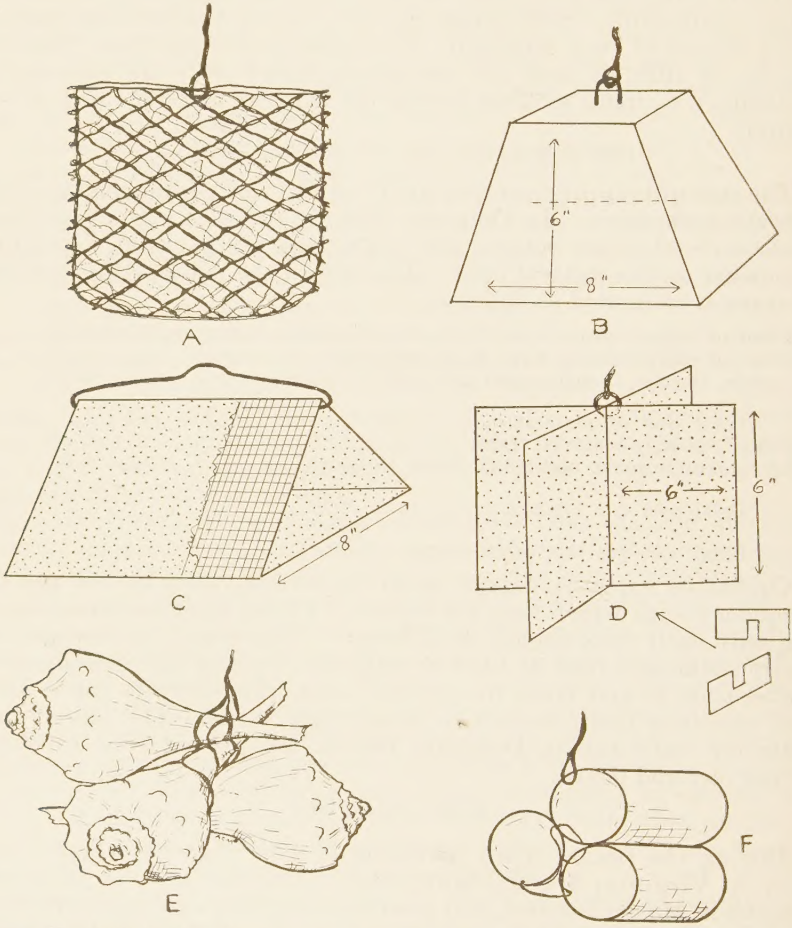

FIGURE 13.—Drill spawn collectors: *A*, wire bag filled with shells; *B*, block composed of shells cemented together with sand and Portland cement; *C*, triangular wire frame plastered with coating of sand and cement (galvanized hardware cloth, ¼-inch mesh); *D*, wire squares plastered with cement (galvanized metal laths); *E*, three large conch shells wired together; *F*, three tin cans wired together.

ARE CONTROL MEASURES WORTH WHILE?

A correct answer to this question can be found by the oysterman himself if he knows the productivity of his grounds and the amount of damages caused by the drills. The benefits to be obtained by trapping, dredging, hand picking on bottoms exposed at low tide, or any other means of control, obviously are determined by the degree of infestation, the value of the wasted oysters, and the cost of mate-

rial and labor employed in the eradication operations. Inasmuch as these things vary greatly from place to place, no generalizations as to methods, cost, or value of drill control can be drawn that will apply everywhere. A solution can always be found, however, if sufficient data on local conditions are at hand.

That drill control is of economic value is obvious from the number of oysters which drills consume. It has been shown that in New Jersey waters each adult drill kills on the average 0.34 oyster per week. Assuming that this rate is applicable throughout the 29½ weeks of the drills' activity in these waters, from April to the end of October, each drill may be held responsible for the destruction of at least 10 adult oysters. Then the removal of 1,393,719 drills from the bay caught in the course of the present investigations should be considered equal to the potential saving of 13.9 million oysters—about 35,000 bushels, valued at the present market price between 34 and 35 thousand dollars.

Operations along the Eastern Shore of Virginia during the 21 weeks from June 15 to November 15 netted 320,438 drills. Of this number 80,838 were removed by hand picking from 60 acres of oyster beds exposed at low tide; the rest were caught with 3,744 wire traps of various designs. Trapping operations lasted only 12 weeks. The maximum catch per trap per week was 489 drills.

At the rate of 10 adult oysters per drill per season some 3,000,000 adult oysters or about 7,500 bushels were thus saved for Virginia oystermen. It is probable that the rate of destruction is higher here than in Delaware Bay because of the higher temperature of the water and the larger size of the drills. This does not include the large number of spat that were saved.

The beneficial results of control can be greatly enhanced by removing drills before the beginning of their spawning season. According to a very conservative estimate each female *Urosalpinx* may lay each season about 252 eggs, which, being well protected have a good chance of hatching. The advantage of an early start in trapping operations is therefore obvious.

Trapping should begin in early spring when the drills show first signs of movement; and should continue until the onset of cold weather in October or November. The most effective time is in July and August.

The efficiency of trapping can be judged by the gradual reduction in the catch of drills over the area of operations. For instance, in Chincoteague Bay in 12 weeks over 45,000 drills were captured; 58 percent of these were caught during the first month; 29 percent during the second month; and 13 percent during the third month. It is reasonable to suppose that the number of drills would further decline if trapping were continued. It is, however, also reasonable to assume that small numbers of drills would always escape traps and would remain on the ground. The continuation of trapping after the catch falls to a very small figure is, however, economically impracticable. The results of the experiments on bottoms from which oysters were removed show that in Chincoteague Bay the use of 25 traps per acre will capture virtually all of the drills in approximately 4½ months.

The stock of seed oysters planted on bottoms cleaned of drills can be protected against future invasion from the surrounding bottoms by leaving an unplanted zone, approximately 20 feet wide, around the replanted area and placing on the outer edge of it a continuous line of traps set from 5 to 8 feet apart. In the field test of this method an average of 5,760 drills per 25 traps was collected over a period of 8 weeks. Subsequent examination of the seeded area showed almost complete absence of drills, thus indicating the practical value of this type of protection.

None of the methods of control discussed above is sufficient in itself to completely eliminate the drills from the oyster bottoms. One should expect, however, that by intelligently combining them and timing their use, a considerable reduction in the abundance of drills can be effected. The exact procedure to be followed should be determined separately for each locality, taking into consideration its geographical position, depth of water, character of the bottom, and the degree of infestation. The general ideal plan, subject to changes depending upon local conditions, can be summarized as follows:

(1) Removal of the oysters from the grounds.

(2) Cleaning the bottom after the removal of oysters by trapping during the summer or dredging with drill dredge throughout the year.

(3) Screening or forking the oysters preparatory to planting them.

(4) Protection of clean planted area by surrounding it with an unplanted zone at the outer edge of which is a line of traps set 5 to 8 feet apart. Also, by setting several lines of traps over the area.

(5) Setting a series of spawn collectors to take up the eggs of the drills, hence to control their propagation.

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